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ON THE MOBILITIES OF GAS IONS IN HIGH ELECTRIC FIELDS

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Up to the present two theories have been advanced to explain the low order of magnitude of the mobility of the ordinary gaseous ion. The first theory known as the 'cluster' theory is due to Langevin.[1] It assumes that the ion consists of a cluster of neutral molecules surrounding an electron or a positive atomion. The second theory was proposed by Wellisch[2] and is known as the 'small ion' theory. This assumes that both positive and negative ions consist of single charged molecules. In its path through the gas such an ion might be retarded abnormally due to the fact that its charge, acting on neutral gas molecules, drags in a greater number of collisions than would an uncharged molecule.

On the 'cluster' theory it would be expected that if the ion acquired sufficient kinetic energy, it would begin to break up. Such energy might be acquired in traversing a mean free path under a sufficiently high field. The break up would then be indicated by an abnormally high mobility. One would certainly expect such a breaking up of the cluster before field strengths great enough to cause ionisation by collision were reached. The other theory would expect no such break up. It is, however, conceivable on the 'small ion' theory that when the kinetic energy reaches a very high value, near that at which ionisation by collision begins, the negative ion might lose its electron. Experiments which were performed by a number of observers on the gas ions at low pressures (i.e., where with a small value of the field the ion can pick up considerable energy on a long mean free path), indicated

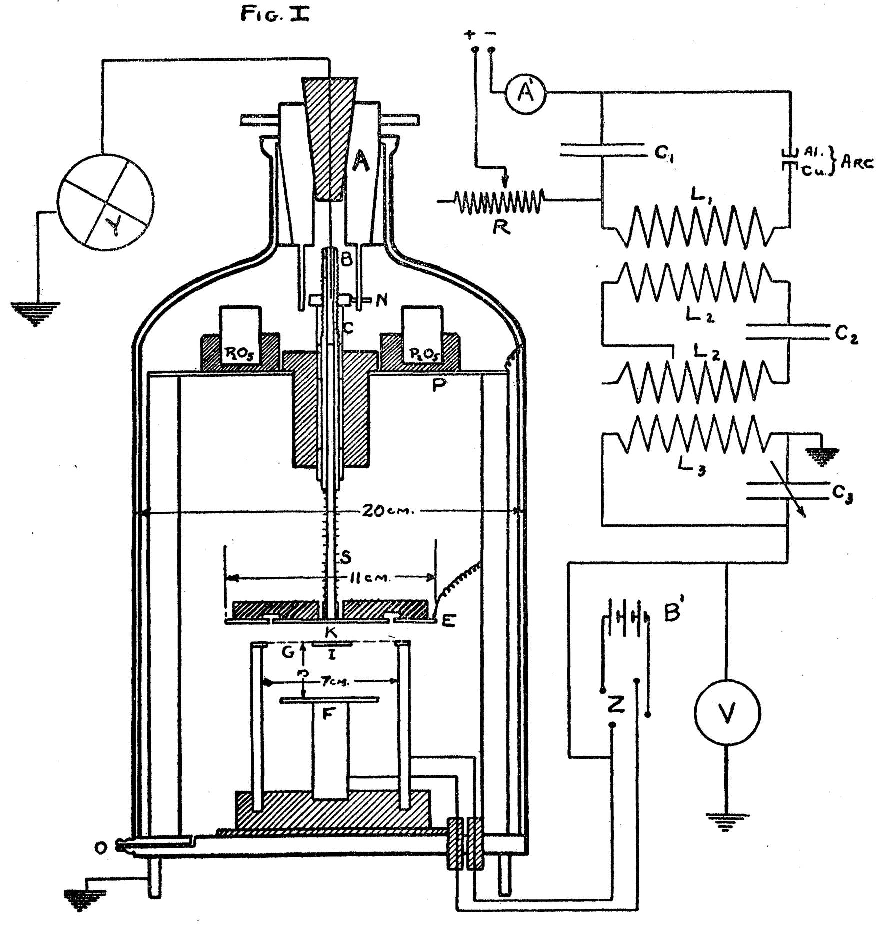
that for the negative ions such a break up did occur. It was consequently thought of importance to see if such a breaking up, or abnormal increase of mobility, of either ion could take place in high electric fields at ordinary pressures. It was considered particularly important to test this point for the case of the positive ion. If in this case an abnormally high mobility were found, only one conclusion could be drawn as to its significance, namely, that the positive ion consists of a cluster. In the case of an abnormally high mobility of the negative ion, the presence of the free electron might make the result ambiguous. It was with this end in view that the work was undertaken at the suggestion of Prof. R. A. Millikan.

Measurements were made by means of the Rutherford[3] alternating current method. With this method the problem resolves itself into one of obtaining high field strengths, e.g., 5000 volts per cm., with alternating fields of frequencies of about 5000 cycles per second. Such frequencies are demanded by the high fields in order to make the distance between the plate and the gauze (i.e., the distance that the ions traverse in one-half cycle), small enough to keep the field between the plate and gauze uniform. These high frequencies were obtained from the resonance circuit of a Chaffee[9] arc. This arc gives nearly undamped sine waves, and is comparatively easy to operate. Using a tertiary circuit as seen in the diagram (fig. 1), an alternating potential difference of 4400 volts at a frequency of 7670 cycles per second was obtained from the arc. The frequency was determined by photographing the spark in a revolving mirror. The mobility-measuring apparatus is similar, as the diagram shows, to that used by other observers. The ions were generated by ionium on a disc I attached to the bottom of the gauze. The whole apparatus was placed inside a silvered bell jar which could be exhausted. Since neither the potential difference nor the frequency could be conveniently varied, the measurements were taken by varying the distance between the plate and the gauze. To do this, the apparatus was so arranged that the upper or electrometer plate could be raised or lowered from the outside of the jar. The distances between the plate and the gauze were plotted as abscissae, and the electrometer deflections as ordinates. The point where this curve intersected the axis of abscissae was taken as the critical distance which the ions could just traverse in the time of one-half period of oscillation. From the value of this distance d, the mobility U of the ion is obtained at once with the aid of the equation $U = \pi N d^2/E$, in which N is the frequency and E the maximum value of the potential.

The measurements were made in air, which was carefully dried

with phosphorous pentoxide in the later measurements. The variations of the values of the mobilities as shown in the table were in a large measure attributable to insufficient drying in the earlier determinations. Fluctuations in the operation of the arc, together with slight uncertainties as to the value of the constants of the alternating potential difference, might possibly have caused an error of ten per

FIG. I



cent in the determination of the absolute value of the mobilities. The actual error, however, is probably much less than this. By means of check determinations, using the 120 volt 60 cycle city alternating potential, which gave strictly normal values of the mobilities, the possibility of any instrumental errors was precluded.

The results obtained are shown in Table 1. In the first column are the frequencies of alternation in cycles per second. In the next

two columns the critical distances in centimeters are given. The next two give the mobilities. The next column gives the pressure in millimeters of mercury. The next columns give the values of the mobilities reduced to 760 mm. pressure. The last two columns give the field strengths for the maximum values of the fields in volts per centimeter.

The measurements were carried up to fields of 12,450 volts per centimeter in air at atmospheric pressure, and to somewhat lower field strengths at pressures as low as 300 mm. of mercury. The results could not be extended to higher field strengths nor lower pressures, because

TABLE I

IONIC MOBILITIES OBTAINED WITH CHAFFEE ARC

N	d_+	d_-	u_+	u_-	p	U_+	U_-	X_+	X_-
					mm.				
60	0.99	1.38	1.10	2.12	760	1.10	2.12	121	87
60	1.00	1.26	1.13	1.78	756	1.12	1.76	120	96
*60	1.00	1.28	1.13	1.85	748	1.12	1.84	118	93
60	1.33	1.56	1.95	2.70	578	1.48	2.05	91	77
7670	0.50		0.97		750	0.98		12,450	
7670	0.55	0.64	1.17	1.59	746	1.19	1.62	11,460	9,750
7670	0.54	0.61	1.07	1.37	747	1.09	1.40	11,550	10,200
7670	0.50	0.65	1.25	1.80	735	1.28	1.86	12,450	9,600
7670	0.66	0.84	1.70	2.74	534	1.27	1.95	9,580	7,430
*7670	0.78	1.02	2.36	4.04	436	1.36	2.32	8,000	6,000
*7670	0.85	1.01	2.72	3.88	430	1.54	2.18	7,346	6,160
7670	0.82	1.10	2.58	4.29	416	1.41	2.29	7,610	5,670
7670	0.85	0.90	2.67	3.07	384	1.35	1.53	7,340	6,910
7670	0.80	0.86	2.51	2.90	382	1.26	1.46	7,800	7,260
†7670	1.11	1.22	4.78	5.80	304	1.96	2.32	5,610	5,160

Mean Mobilities at 760 mm. 1.33 1.89

* These readings were taken with very dry air.

† The value of the + mobility only estimated here, not determined.

of the fact that irregularities in the operation of the arc caused serious sparking beyond these limits. It can be clearly seen that for a range of field strengths extending from 90 volts per centimeter to 12,450 per centimeter in air at atmospheric pressure, *there is neither for the positive nor the negative ion any marked increase in the absolute value of the mobility. It is also to be noticed that the mobility of the negative ion shows no abnormal increase relative to that of the positive ion.* In other words, in fields of nearly half the value of the sparking field strength in air (30,000 volts per centimeter at 760 mm. pressure), and in fields where occasional sparking did actually occur (due to irregularities of

the arc), one *finds that the mobilities are absolutely normal.* Even at pressures as low as 300 mm., where the potential fall per mean free path is larger still, there is no abnormal mobility.

These results as regards the mobility of the positive ion for high values of the product, field strength times mean free path, seem to be in direct contradiction to the results of Todd,[4] who, working at very low pressures and small field strengths, got an apparent abnormal increase in the mobility of the positive ion. The value of this product may be expressed as the ratio X/p, to which it is proportional, where X is field strength in volts per centimeter and p is the pressure in millimeters of mercury. The value of X/p for which Todd[4] observed the abnormality of the positive ions is 2.6. The values of X/p at which I worked are as high as 18.0. The latter's results agree, however, with those of Wellisch[5] recently obtained at pressures as low as 0.05 mm. of mercury. Wellisch[5] found no abnormal mobilities of the positive ions for values of X/p as high as 34.5. This value of X/p is close to that for ionisation by collision at this pressure.

The results obtained by me with negative ions for high pressure for values of X/p near where ionisation by collision must begin, seem to be contrary to the results of most of the observers who worked at low pressures with much smaller values of X/p. Townsend,[6] basing his assertions on the work of Lattey,[7] states that for low pressures the abnormal mobility, i.e., the breaking up of the cluster, should begin at $X/p = 0.1$. This appears to be in direct contradiction to the results of the writer obtained with air at pressures as low as 300 mm., and with $X/p = 16.0$, where strictly normal negative mobilities are found. In view of this contradiction, I worked over the results of Kovarick,[8] who obtained abnormally high negative mobilities at low pressures, to see whether the appearance of the abnormally high mobilities in his work was a function of X/p. The initiation of these abnormal mobilities was found to be a function of p rather than of X/p, which indicated, since my pressures were much higher than Kovarick's,[8] that the two sets of results were not necessarily in conflict.

All of the above facts are in accord with the recent results of Wellisch[5] on the mobilities of negative ions at low pressures. He found that, even at the lowest pressures at which he worked, the negative carriers were in part at least perfectly normal negative ions. This was the case for values of X/p close to the value of X/p for ionisation by collision at those pressures. He also found increasingly great numbers of free electrons in air as the pressure was reduced below 8 cm., but no intermediate negative ions. These free electrons could not, according to Wellisch,

be detected by the other observers because of their low frequencies of alternation. The result was that the curves of these observers gave them apparent abnormal increases in the mobility of the negative ion, which increased in value with decreasing pressures. In my experiments these electrons were of course absent, and so no apparent abnormal increase was obtained.

The conclusion to be drawn from these results seems to be that the 'cluster' theory, which has until now been most generally accepted, is not correct. This forces us to accept the 'small ion' theory in some form or other.

Summary.—1. The mobilities of positive ions have been determined in electric fields very nearly strong enough to cause ionisation by collision at atmospheric pressures and have been found to be perfectly normal within the limits of error of the measurement.

2. The mobilities of the negative ions have also been determined, under the same circumstances, with the result that they not only showed no relative abnormal increase in value over those of the positive ion, but also showed a perfectly normal absolute value of the mobility.

3. These results, though at variance with those of most observers at low pressures for the negative ions, are in good agreement with recent results of Wellisch,[5] and likewise lead to the conclusion that the 'cluster' theory is no longer tenable.

[1] Langevin, Thesis, *Ann. Chim. Phys., Paris*, 1902.
[2] Wellisch, *London, Phil. Trans. R. Soc.*, A, **209** (1909).
[3] Rutherford, *Cambridge, Proc. Phil. Soc.*, 1898.
[4] Todd, *Phil. Mag., London*, June, 1913.
[5] Wellisch, *Amer. J. Sci., New Haven*, May, 1915.
[6] Townsend, *Electricity in Gases*, 1914.
[7] Lattey, *London, Proc. R. Soc.*, A, **84**, 1910.
[8] Kovarick, *Physic. Rev., Ithaca*, 1911.
[9] Chaffee, *Boston, Proc. Amer. Acad.*, **47**, No. 9, 1911.

THE RELATION OF MYELIN TO THE LOSS OF WATER IN THE MAMMALIAN NERVOUS SYSTEM WITH ADVANCING AGE

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Starting from birth, the water-content of the mammalian body diminishes with age, and the same statement holds for the several anatomical systems which compose the body (Lowrey[1]). My own studies have been made on the albino rat in which the changes in the water-